Chapter 9

Biogas Production Plants: A Methodological Approach for Occupational Health and Safety Improvement

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Additional information is available at the end of the chapter

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Abstract

Existing lessons on public safety, referred to as new biotech plants, suggest that the development of effective, responsive and responsible safety standard can improve the trust of the public in the new generation plants such as biorefineries. This implies the need for specific risk assessment aimed at defining the mitigation measures, which can minimize the impact of hazards on workers' health. The main hazards, referred to biogas production process, are biohazard, fires and potentially explosive atmospheres. In particular, the last two hazards strictly depend on the presence of methane in the biofuel. This chapter presents the results of a work aimed at providing the biogas industry with a practical tool, which can be used to carry out the analysis of hazards of biogas plants. The adopted method for developing the tool is based on the well-known checklist approach. The checklist is a valuable support for the plant operator to evaluate periodically the actual effectiveness of the overall safety measures and ensure a safer management of the biogas plant. The checklist can meet these requirements. This chapter reports the main preventive, protective and managerial measures, which can be adopted to decrease the hazardous outcomes on workers' health and safety.

Keywords: biogas, biohazard, potentially explosive atmospheres, fire, checklist

1. Introduction

The renewable energy sources, that have been well developed in Italy, include biogas, which is mainly obtained from the anaerobic digestion (AD) of agricultural and livestock biomasses. Italy is the second biogas producer in Europe, after Germany, and by the end of 2015, about 1555 biogas plants were operating, of which 77% were powered by agricultural matrices [1]. Biomethane production from biowaste is also an important contributor to reach the objectives established by the European Directive 2009/28/EC on renewable energies [2]. The Italian decree on incentives for producing biomethane opens new development perspectives for renewable energies from biowaste, as this biofuel could be used in vehicles as a substitute for fossil fuel and replace the natural gas dependence in domestic, commercial as well as industrial consumptions [3]. Most of the biogas production plants are of small or medium size, therefore, falling below the thresholds for the application of legislation aimed at the control of major accidents, as the Seveso Directive [4]. In Italy, in 2010, there were approximately 100,000 workers in green industries, and it is expected that the number will reach 250,000 units in 2020 and most of them will be involved in bioenergy industry. Green jobs are activities characterized by previously evaluated risks but with a different scope and exposition in connection with newly applied technology [5]. However, it is important to complete an evaluation process with respect to new or re-emergent risks in the biorefineries [6]. The transformation of such plants, from only agricultural and livestock to energy production, introduced a different risk profile for the operators. This aspect is generally underestimated for occupational health and safety (OHS) management, and the large number of plants maintain the same individual risk evaluation that they followed for the operators before transforming the plant. A European database of accidents (mainly explosions), related to biogas production, has been recently created and data on about 170 accidents have been collected from different literature sources [7]. It is necessary to integrate the OHS issues at an early stage of development of the industrial process [8]. The principal reason behind any OHS risk assessment activity is to undertake a proactive and systematic analysis of health hazards in the workplace in order to appropriate the control measures. The management of OHS must be in accordance with the general principles, which should be applied to control workplace hazards in order to:

(a) eliminate the risks;

(b) assess the risks, which cannot be avoided;

(c) reduce the risk at source;

(d) give priority to collective protective measures over individual protective measures;

(e) adapt the work to the individual, especially with regard to the design of workplaces and the choice of work equipment and production methods;

(f) adapt working methods to technical progress;

(g) develop a coherent overall prevention policy, which covers technology and work organization and

(h) give appropriate instructions to employees.

Even though biogas plants are considered quite simple in installation, they feature a variety of items. As there are many feedstock types, which are suitable to anaerobic digestion (AD) in the biogas plants (biomass from dedicated crops, vegetable waste, sludge, residues of livestock farming such as manure or slurry, organic fraction of municipal solid waste, etc.), there are various techniques for treating these feedstock types and different digester constructions and systems of operation. This implies the need to carry out a specific risk assessment in order to define risk prevention and mitigation measures aimed at minimizing the impact of biohazard on workers' health. In the biogas production supply chain, various work-linked risks can be identified such as explosion, fire and biological risks. In connection with used materials, including vegetables, food production residuals and animal biomasses, as well as with the properties of fermentation, biological risk deserves particular attention. Fermentation biomass is rich in microorganisms, including pathogens and opportunistic pathogens, and anaerobic processes could lead to the selection of microbial flora, which can promote the presence of anaerobic microorganisms, for example, *Clostridia*, that initially are less represented [9]. Epidemiological data in the field of workers' exposure to the organic dust showed specific occupational diseases, such as respiratory tract disorders (airways inflammation, bronchitis, asthma); gastrointestinal problems (from nausea to diarrhoea) and skin, eyes, nose and airways allergic reactions. In the 1990s, for example, it was found that gastrointestinal diseases were more common among workers of refuse-derived fuel plants [10]. This chapter presents the results of a work aimed at providing the biogas industry with a practical tool, which is able to protect its workers. Biological contamination, fire and potentially explosive atmospheres are the main hazards referred to the biogas production. On this subject, it is essential to take into account that the typical culture of farming is far enough from industrial approach and therefore it requires clear and useful tools, which are able to address both elements—maintenance and operation. The work has allowed to define technical and organizational measures aimed at preventing and mitigating the hazards. From this analysis, a structured safety checklist has been derived. This checklist is a valuable support for the plant operator to evaluate periodically the actual effectiveness of the overall safety measures and to ensure a safer management of the biogas plant.

2. Material and methods

The adopted method for developing the required tool is based on the well-known checklist approach. At the beginning, the initial events (biological contamination, fire and explosion), which could cause an adverse effect on workers (injuries or diseases), were identified. The next step was focused on identification of measures aimed at preventing the workers from getting affected by a potential 'initial event'. In succession, protection measures were subsequently identified to reduce the 'dose', which is received by the worker exposed to the initial event. The event mitigation was aimed at:

- minimizing the amount of hazardous agent;
- protecting workers from hazardous phenomenon and
- minimizing the duration of exposure.

The 'safety checklist' has been derived from organizational and procedural measures and technical systems. The discrimination of protective and preventive measures are highly valuable to define the safety devices' importance; assess and monitor safety levels and take adequate decisions about training, maintenance schedule and safety investments. The checklist has been divided into three sections referred to as biohazard, fire and explosion risk. Each section reports preventive, protective and managerial measures. The checklist has to be considered as a very important tool aimed at evaluating the actual efficiency of safety measures.

3. Biohazard

Biohazard in the production of biogas may be related to feedstock and digestate. Wastes of animal and human origin contain various pathogenic bacteria (e.g. *Salmonella*, *Enterobacter*, *Clostridia*, *Listeria*), parasites (e.g. *Ascaris*, *Trichostrongylidae*, *Coccidae*), fungi, viruses [11, 12] and could represent an occupational biohazard. In the biogas production from co-digestion of animal manure and biogenic wastes, the microbiological quality of raw materials of animal origin is guaranteed only through the application of specific veterinary and sanitary measures (e.g. control of livestock health, hygiene control of raw materials entering the digester). High-risk biomasses such as those from sick animals must be excluded from use; for biomass categories such as slaughterhouse residues, pre-sanitation measures are required through pasteurization or sterilization as stipulated by European Regulation EC 1069/2009 [13]. In case of feedstock categories, which do not require separate pre-sanitation, the combination of AD process temperature and a minimum guaranteed retention time provides an effective pathogen reduction/inactivation in the digestate [14]. In Italy, the digestate quality standard is monitored by several checkpoints [15]. In a biogas plant, exposure levels to biological agents are highly dependent on site activities and tasks undertaken by workers. It is the site operator's responsibility to identify potential hazards, carry out suitable risk assessments and provide adequate protection to their workforce to control such risks. During AD, the microbial reactions take place inside the digester under containment conditions and, therefore, there is no workers' exposure. However, activities such as inoculation, sampling and harvesting the microbial flora during the monitoring of the fermentation process, could involve worker exposure and, therefore, the workers' activities should be checked to define the exposure characteristics. According to European classification, the microorganisms with infection potential, which take part in the anaerobic fermentation process, are mainly assigned to the risk group 1 and to a small extent to the risk group 2 [16]. Some of these microorganisms should be considered opportunistic agents, which do not cause any infections in healthy employees, but they can lead to diseases when body defences are defective. In general, good work practices and simple but effective personal hygiene measures are sufficient to prevent workers from infection risk, including provision of adequate hand-washing facilities. Biological risk assessment should take into account that specific activities, such as biomass reception, temporary storage, biomass handling, digestion drainage and maintenance work, may pose exposure risks to organic dust, bioaerosol and biological components conveyed such as particulates (i.e. bacterial endotoxins, fungal spores). Evidence from epidemiological data shows that these biological agents can cause allergic reactions such as hypersensitivity pneumonitis, allergic rhinitis, some types of asthma and organic dust toxic syndrome (ODTS) [17]. In Italy, the biogas industry expansion is quite recent, and there are not many data available on biological risk in these plants. Recent findings on airborne workers' exposure in two full-scale plants of anaerobic digestion in North Italy showed different biological contamination levels in relation to the involved biomasses (silage, vegetable waste, animal slurry and biomass from dedicated crops) and to the technological and building characteristics [18]. This evidence suggests that every biogas plant requires a specific approach. Contamination and occupational risk must be evaluated individually for each plant, because numerous variables influence risk magnitude, with particular regard to digested sludge treatments, such as input biomass nature, storage, movement conditions, building configuration and technological processes [18]. The results of the air microbiological monitoring, performed during the biomass movement in some biogas plants investigated in Italy, showed that organic dust (PM_{10}) and its endotoxin content are limited [18] and widely below the occupational safe guidelines [19, 20]. The particulate is not a relevant risk for workers in the plants monitored, because it reached rural environmental levels recorded in North Italy [18].

3.1. Biological risk assessment

The assessment of biological risks is seriously hampered, since neither universally approved criteria for assessing exposure to biological agents nor agreed dose-response estimates and occupational exposure limits (OELs) are yet available. Lack of a standardized sampling methodology has made it difficult to compare data derived from different studies and relate exposure levels to effects on health. Potential seasonal variation of microbial exposures also adds difficulties in comparing data. Establishing the prevalence and incidence rates of diseases related to exposure to biological agents is not easy: data on occupational diseases from biological agents are difficult to collect, because the infections could often be in subclinical form, with atypical incubation periods and/or transmission routes [21]. Moreover, the exact role which, is played by biological agents in the development or aggravation of symptoms and diseases, is only poorly understood. Human response to exposure to biological agents depends on the organic material involved and individual's susceptibility to infections and allergies. In addition, microorganisms constantly interact with the environment and are able to modify their pattern of gene expression rapidly in response to the environmental signals [21]. A variable human response has also been described, following the exposure to organic dust in different workplace settings, and it was shown that the composition of the dust may play an important role in determining the potency [22]. The assessment of biological risk in the biogas sector is a complex task, even considering that the biogas industry is still in its infancy in some countries such as Italy. Limited public domain information is also available from ongoing health and injury surveillance of biogas workers, particularly for health outcomes of highest concern (e.g. respiratory, irritation, sensitization). There is a need for improving the collection of work-related diseases in the biogas sector, and an ad-hoc accident reporting system should be created.

The proposed approach for biological risk assessment is that certain areas or activities, resulting from the biogas industry, could be categorized using fairly simple descriptive expressions of risk and a corresponding set of control measures, which depend on the perceived risk associated with the area or the activity. The qualitative checklist approach can represent a reasonable tool in order to overcome the current knowledge gaps in establishing agreed monitoring protocols and developing reliable dose-response data. In absence of such information, the potential risk should be managed in a precautionary manner. Exposure levels to biological agents are highly dependent on site activities and tasks undertaken by workers, and an adequate workers' protection requires a detailed site and task risk assessment. Potential exposure can be controlled by changing the work process to minimize the generation of bioaerosols or dustiness. In order to achieve compliance, employers should demonstrate that adequate control measures have been developed in accordance with the hierarchy of controls, detailed in the Directive 2000/54/EC [16]. Examples of control measures are exhaust ventilation to prevent exposure, adequate filters on the air intakes of vehicles (such as tractors used to move biomass) and personal protective equipment, such as suitably fitted respiratory devices, when working in areas close to where bioaerosols are generated.

3.2. Prevention and protection measures for occupational biohazard

Design of workplaces and work processes, the choice of adequate equipment and working methods allow the control of occupational biohazard in the biogas plants. Any activities involving the movement of biomass and/or waste should be controlled, and site design and activities should be managed to avoid organic dust and/or bioaerosol release in the workplace. In particular, the biomass, such as silage, should be stored in closed silos or in platforms provided with containment walls and covered by a plastic material wrap. Livestock slurry storage tank should be equipped with immersion agitators to avoid air contamination, and moreover, the automatic transfer of slurry into the digester should be guaranteed by a pumping system. Working areas, where biomass is moved, should be considered as potential high exposure zones. An efficient system of forced ventilation is required if high-exposure activities are conducted within a confined space and, where practicable, employees should only work in these areas within a suitably controlled environment, such as a vehicle cab, or wear appropriate respiratory protective equipment (RPE). It is recommended that for exposure to bioaerosols, RPE is provided with the highest efficiency filters (P3). The replacement of the filters in the vehicle cabs' air handling system, cleaning of vehicle cabs and the instructions given to operators not to open cab doors and windows and remain in the vehicle have a significant effect on workers' exposure levels. These rules should be applied within a radius of 50 m from the operational areas, considering that bioaerosol levels typically return to background concentrations within this distance [23]. Such requirements clearly have an impact on site design and layout. In order to achieve these targets, the employers should amend working practices and operations and relocate office accommodation and welfare facilities to an area outside the potentially high-exposure zones. Dust control from the movement of vehicles is also recommended, and roadways should be properly constructed so that they can be cleaned and a vehicle wheels washing system should be planned. The workplace should be provided with adequate hand-washing and shower facilities and 'clean areas' in order to ensure that no contamination can affect external places. Employers should undertake an appropriate health surveillance of their workforce to ensure that early signs and symptoms of diseases, related to exposure to biological agents, are managed and reported. This may involve simple health screening or more detailed assessments, involving health questionnaires, lung function and blood serum test. All employees, who have undertaken health surveillance, should have a personal health record and the information must be kept for a period of 40 years and the findings of any health surveillance should be communicated to employees and any adverse findings should be deeply investigated and appropriate controls should be adopted. The training of site managers and personnel is a fundamental topic in order to verify the design and implementation of these prevention measures. It must be stressed that appropriate instructions, information and training, referred to the potential risks to their health and how they should be controlled, must be given to employees. Employers should also develop procedures for people who do not comply with the procedures and site rules.

4. Explosion risk: formation of potentially explosive atmospheres

Because of the presence of methane in its composition, biogas in combination with air can form potentially explosive atmospheres (**Table 1**). In Europe, safety measures against explosion risk are stipulated in Atex Directives 99/92/EC [24] and 2014/34/EU, which have inspired the preparation of checklist section, referred to the explosion risk. A crucial topic, reported in safety checklist, is the classification of plant areas [25], where explosive mixtures could be generated by biogas releases. This classification has to be carried out in terms of zones (Zone 0, Zone 1 and Zone 2), geometrical characterization (extent and volume) of hazardous areas [26] and persistence time:

1) **Zone 0**: an area in which an explosive gas atmosphere is present for long periods;
2) **Zone 1**: an area in which an explosive gas atmosphere can periodically occur during the normal operation and
3) **Zone 2**: an area in which an explosive gas atmosphere is not expected during the normal operation, but if it should occur, it would exist for a short period.

Directive 99/92/EC states that, places where potentially explosive atmospheres can occur are marked with specific signs (**Figure 1**), which are characterized by the following distinctive features:

- triangular shape and
- black letters on a yellow background with black edging

In **Figures 2** and **3**, the classification procedure of hazardous areas (outdoor and indoor place) is shown. It may be used as a basis to support the proper selection and installation of work equipments in hazardous zones. Classification of indoor places is particularly important because ventilation system design plays a fundamental role in order to dilute the potentially explosive atmosphere in the shortest times.

The first step of classification procedure consists of locating the potential sources of biogas release. On this subject, it has to be remembered that catastrophic elements failures are not considered as potential sources because they are beyond the concept of abnormality [27], reported in Technical Standards.

A plant component, such as valves, flanges, pumps, compressors, and so on, is considered as a potential source when its failures are expected during the operation. Zone classification depends on source release grade, ventilation degree and availability. Release grade

	Unit	Biogas (60% CH_4, 40% CO_2)	Methane	Natural gas
Heat value	kWh/m^3	6	10	10
Ignition temperature	°C	700	600	650
Explosion range	Vol (%)	7.3–28.3	4.4–16.5	4.4–15

Table 1. Properties of gases.

Figure 1. Sign (zone where potentially explosive atmospheres can occur).

(continuous, primary, secondary) is determined by the analysis of element operating conditions [28]. On the contrary, ventilation degree depends on the volume of explosive atmosphere, which is strongly influenced by biogas mass flow. This last parameter depends on gas outflow typology (sonic or subsonic), which is determined by the comparison between critical pressure (p_{cr}) and atmospheric pressure (p_a):

- $p_{cr} > p_a \rightarrow$ (sonic outflow)
- $p_{cr} < p_a \rightarrow$ (subsonic outflow)

Ventilation degree can be high or medium for outdoor places, whereas it can be high or medium or low for indoor places. Three levels of ventilation availability are reported in Technical Standard (EN 60079-10-1):

Good: ventilation is continuously present;

Fair: ventilation is expected to be present during normal operation and its discontinuities are permitted, but they have to occur infrequently or for short periods and

Poor: ventilation, which does not meet the standard of fair or good.

Ventilation availability can be good or fair for outdoor zones, whereas it can be good or fair or poor for indoor areas. For outdoor places, this parameter depends on local minimum wind speed. If wind speed is bigger than 0.5 m/s, ventilation availability can be considered as good. For indoor areas, in order to assess ventilation availability, reliability of artificial ventilation system and presence of standby fans or an emergency ventilation plant has to be ensured. In case of fan failure, good availability usually requires automatic start-up of standby fan(s). Indoor areas are the most

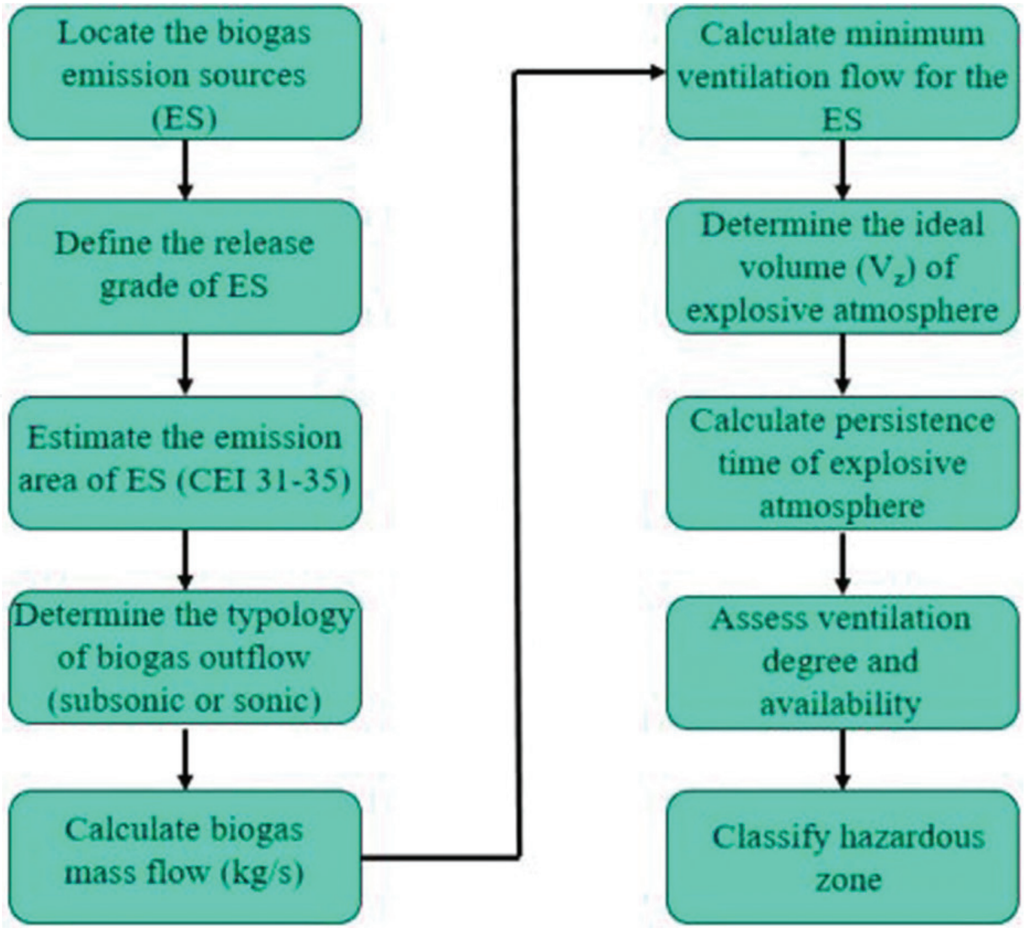

Figure 2. Classification of an outdoor place.

hazardous places with regard to formation of explosive mixtures. In a biogas production plant, a potentially dangerous zone is the container (indoor place), which includes combined heat and power (CHP) unit (**Figure 4**). In indoor places, in order to assess the ventilation degree, sources emission contemporaneity must be considered. This is a necessary condition aimed at calculating average biogas concentration (X_m%) in indoor areas. X_m% depends on source release grade and can be calculated according to IEC 31-35 (Technical Standard). In case of continuous grade emissions (temporary period can be negligible), X_m% is calculated by the following equation:

$$X_m\,\% = \frac{M_{gas}}{Q_a \cdot \rho_{gas}} \cdot 100 \tag{1}$$

where:

- M_{gas} (kg/s) is biogas mass flow;
- Q_a (m^3/s) indicates ventilation air flow; and
- ρ_{gas} (kg/m^3) is the biogas density.

In case of primary and secondary grade releases (temporary period is considered), X_m% is calculated by the following expression:

$$X_m\,\% = \frac{M_{gas}}{Q_a \cdot \rho_{gas}} \cdot (1 - e^{-C \cdot t_E}) \cdot 100 \tag{2}$$

where:

- C (s^{-1}) represents the number of fresh air changes per time; and
- t_E (s) is the release duration.

Table 2, which is reported [26] in EN 60079-10-1, is used to classify the hazardous zones.

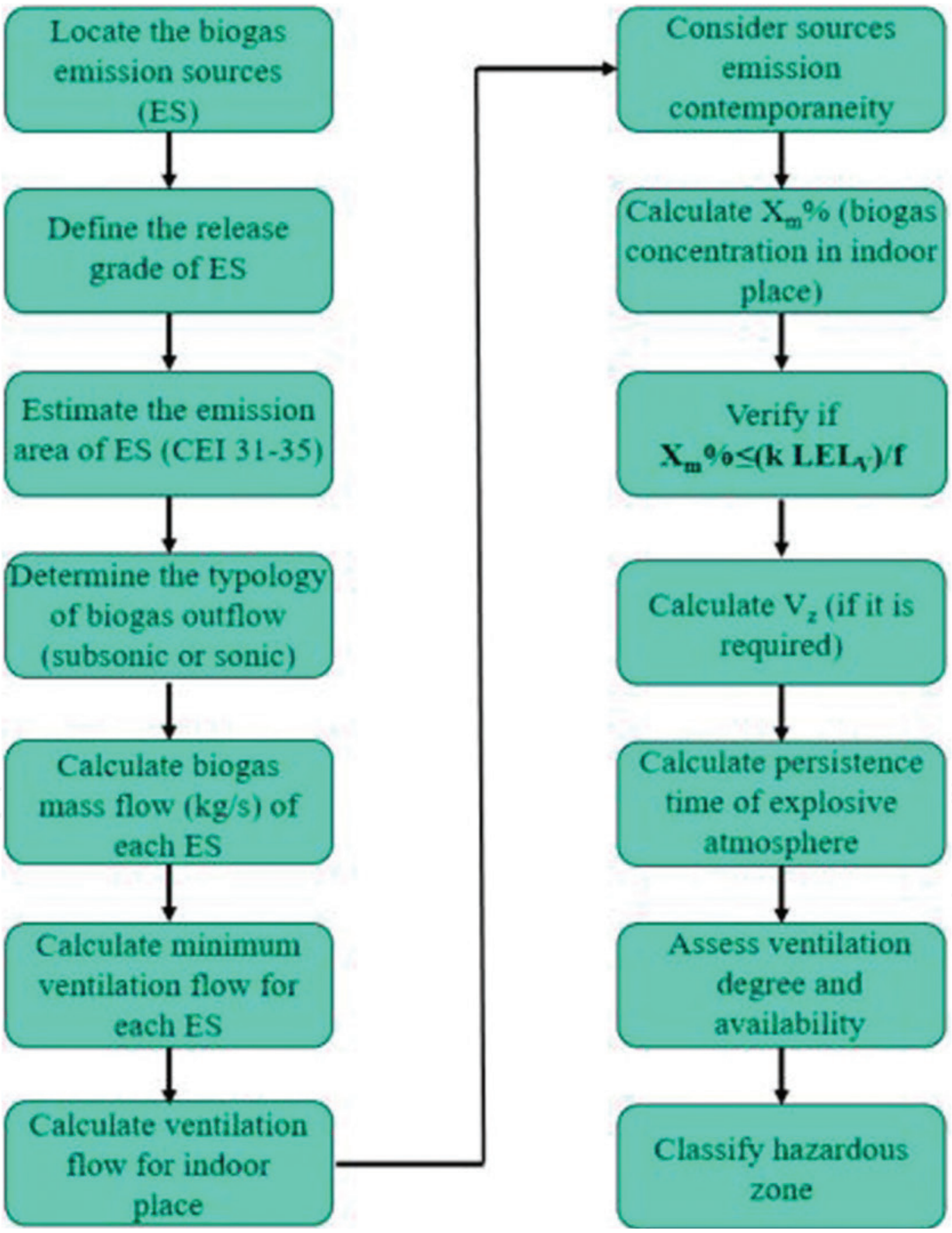

Figure 3. Classification of an indoor place.

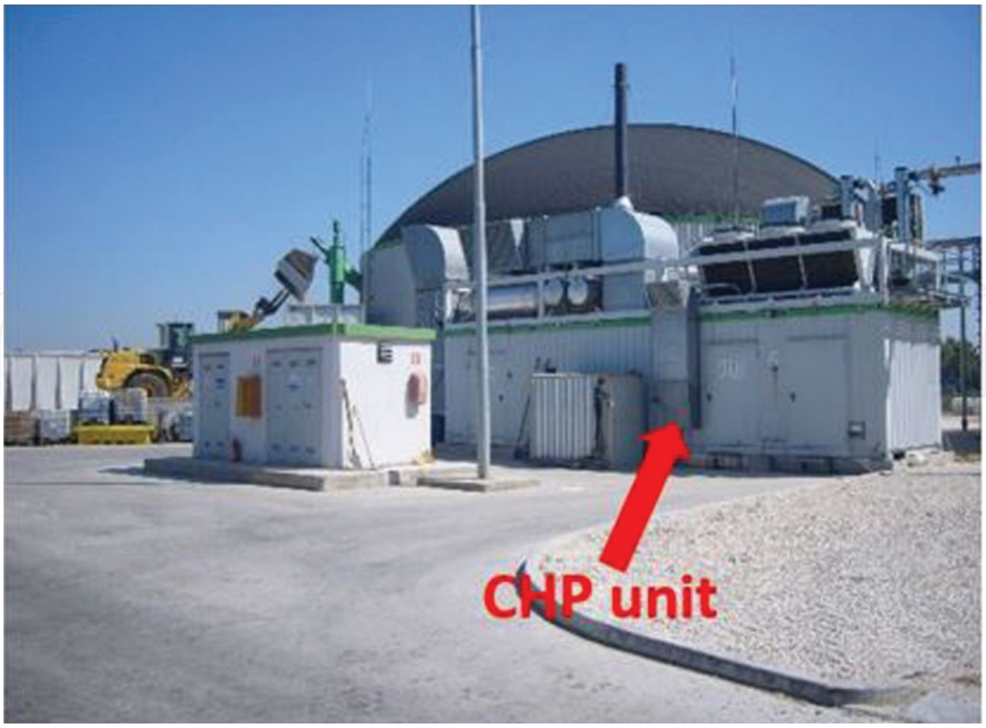

Figure 4. Combined heat and power unit (indoor place)—Source: Maccarese S.p.a.

	Ventilation						
Release grade	**Degree**						
	High			**Medium**		**Low**	
	Availability						
	Good	**Fair**	**Poor**	**Good**	**Fair**	**Poor**	**Good, fair or poor**
Continuous	(Zone 0 NE) Non-hazardous zone[a]	(Zone 0 NE) Zone 2[a]	(Zone 0 NE) Zone 1[a]	Zone 0	Zone 0 + Zone 2	Zone 0 + Zone 1	Zone 0
Primary	(Zone 1 NE) Non-hazardous zone[a]	(Zone 1 NE) Zone 2[a]	(Zone 1 NE) Zone 2[a]	Zone 1	Zone 1 + Zone 2	Zone 1 + Zone 2	Zone 1 or Zone 0[b]
Secondary	(Zone 2 NE) Non-hazardous zone[a]	(Zone 2 NE) Non-hazardous zone[a]	Zone 2	Zone 2	Zone 2	Zone 2	Zone 1 or Zone 0[b]

Glossary: '+' means 'surrounded by'.

[a]Zone 0 NE, 1 NE or 2 NE indicate areas, which have negligible extents.

[b]Zone 0 can be generated in poor states of ventilation.

Table 2. Classification of hazardous zones.

5. Fire risk

In order to reduce the fire risk, the safety checklist suggests several recommendations and actions, which consist of prevention, protection and managerial measures. By reason of space, the checklist only shows the most important points related to fire risk. In order to minimize the fire effects, biogas production plant has to be divided into fire protection sectors [29], for example, the anaerobic digester, the biogas holder and CHP unit. Certain distances must be maintained among these sectors. In particular, during the biogas holder construction, specific safety distances must be ensured (internal and external safety distance and protection distance).

6. Results and discussion

By reason of space, the safety checklist only reports the most important bullet points referred to as the three examined hazards (**Tables 3–5**).

The safety checklist for the biogas industry can support the hazards identification and the definition of the prevention and protection measures and, if used in the right way, forms a basic part of risk assessment. It is essential that the checklist is used as a means of development

Biohazard assessment
Are there operations/tasks, which may result in bioaerosol, organic dust or particulate dispersion (biomass reception, its storage, grinding, shredding or other pre-processes of the biomass, digester loading operations, digestion drainage, sampling activity or maintenance work)?
Are high-exposure activities performed within indoor places?
Are the work processes designed to reduce the releases of organic dust and bioaerosol in the workplace?
Is the biomass stored in closed containers/tanks?
Are there leakages of solids or leachate during the handling phases of the materials entering and leaving the system?
Do workers have direct contact with manure, slurry or other organic waste?
Are there risks of splashes and spills contaminated with biological agents?
Are workers particularly subject to the risk of infective or immunological diseases (workers with particular allergies or asthma, low immune system, pregnant women)?
Prevention and protection measures
In indoor places, are collective protection measures applied to the source of the biohazard, such as ventilation systems and appropriate work organization procedures?
Is the workplace regularly cleaned? Are operating procedures defined?
Is the **workplace** provided with hand-washing and shower facilities and 'clean areas'?
Is eating and drinking forbidden in the workplace?
Are warning and safety signs used at the workplace? Do workers have difficulty of national language understanding?
Do workers receive information on biohazards and protective measures before assuming their tasks?
Are vehicles, circulating in the biogas plant, subjected to regular washing?

Is the vehicle cab equipped with dedicated ventilation systems? Is the monitoring of the door seals and the filter maintenance provided?
Are workers provided with respiratory protective equipment (RPE) during high-exposure activities?
Do workers carry out trainings focused on the right use of individual protection devices?
Is it verified that the defined procedures are actually observed by the workers?
Are workers under health surveillance?
Are workers informed of the significance of health assessments and their outcomes?
Is there a system which reports the accidents and records the episodes of contamination with biological agents (even mild)?
Are workers aware of the importance of recording any contamination episodes?

Table 3. 'Safety checklist' extract: biohazard.

Explosion risk
Prevention measures
Are places with explosion risk classified into zones (0, 1 and 2) according to the probability of occurrence of potentially explosive atmosphere?
Are hazardous zones (0, 1 and 2) characterized in terms of volume and extent?
Is persistence time of explosive atmosphere calculated?
Are suitable ventilation rates ensured in indoor places in order to dilute biogas concentration below lower explosive limit?
Are standby fans or an emergency ventilation system installed in indoor workplaces (container of CHP unit)?
Are there adequate openings aimed at ensuring a good natural ventilation in indoor workplaces?
Are wind action and stack effect taken into account for dimensioning the openings of indoor workplaces (natural ventilation)?
Are work equipments and protective devices selected on the basis of categories set out in Directive 2014/34/EU?
Is all process control equipment classified according to European Standards?
Is the air flow, injected for biological desulphurization, matched with the current rate of biogas production (max. 6% volume)?
Protection measures
Can a biogas release be diverted **or** removed to a safe place or, if that is not practicable, safely contained by other suitable methods?
Are flame arresters installed in biogas pipes?
Are **biogas holders** equipped with positive (hydraulic seal) and negative pressure protection devices?
Is the water filling of pressure safety devices daily controlled and is the correct water level maintained?
Are all closed tanks, in which fermentation can occur, provided with pressure safety devices?
Managerial measures
Are workers equipped with working clothes which do not generate electrostatic charges?

Explosion risk
Are hazardous areas indicated by specific signals?
Is there an obligatory journal **for the documentation** of all daily measurements, controls and maintenance works as well as failures?
Is there a plan indicating the explosion protection zones?
Is it certain that an operational manual is available before any work is done?
Is it established in the manual that safety devices have to be checked at least once a week and after any failure?
Is the engine (CHP unit) maintained according to the timetable given by the manufacturer?
Is the CHP unit maintained or checked by specialized companies?
Are all parts of the biogas plant, containing a gas flow, regularly checked and submitted to a pressure test at least every year?
Are operating instructions readily available, easy to see and read by the operators during their work?
Is artificial ventilation system of container, which includes CHP unit, maintained and checked according to the timetable given by the manufacturer and if necessary is it maintained or checked by specialized companies?

Table 4. 'Safety checklist' extract: explosion risk.

Fire risk
Prevention measures
Are biogas holder membranes made of fire-resistant materials?
Do biogas holder membranes avoid the formation of electrostatic charges?
Are electrical equipments designed in accordance with Regulations and Technical Standards?
Are electrical equipments provided with protective grounding?
Are biogas holders protected from lightning?
Is the storage of flammable materials, flammable liquids and gases limited to small amounts?
Protection measures
Are biogas pipes insulated to give protection against fire and provided with fire protection flaps?
Is the protection distance respected during the biogas holder placing?
Is the internal safety distance respected during the biogas holder placing?
Is the external safety distance respected during the biogas holder placing?
Are there enough fire extinguishers on plant site?
Are there gas/fire detectors, which sound an alarm in case of fire?
Are the hydrants chosen in accordance with Technical Standards in terms of flow and pressure?
Is an additional generator, aimed at ensuring electric delivery in case of failures, installed?
Managerial measures
Is a responsible person designated for all fire protection measures?
Are fire protection exercises regularly carried out?

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Fire risk
Are smoking, naked flames and storage of flammable materials forbidden in the plant area?
Is firefighting system maintenance regularly carried out in accordance with the reported directions?
Are maintenance operations reported in a specific register?
Is electrical equipment maintenance regularly carried out?
Are there adequate and well-marked routes for fire brigade vehicles?
Are fire protection posts set up and suitable fire extinguishers made available when works (welding, abrasive cutting, etc.), which involve a fire risk, are carried out?
Are firefighting systems periodically checked?
Are gas sensors/fire detectors periodically checked?
Is it certain that the operation and maintenance of biogas plant is done by reliable and qualified persons?

Table 5. 'Safety checklist' extract: fire risk.

support and not simply as a 'tick off-the-box' exercise. A specific sector guidance, referred to the potential risks to biogas plants workers health and their assessment and management, is required, and it is likely that site operators will be in need of specialist advice to carry out an effective risk assessment and develop risk control procedures. In this context, the reported checklist can improve the safety culture in the biogas field. In conclusion, it has to be stressed that the safety checklist has been tested in some biogas production plants, where inspections and audit activities were simulated in order to verify its real feasibility.

7. Conclusions

Countries of the European Union (EU) have agreed on a new 2030 Framework for climate and energy, which includes targets and policy objectives for the period between 2020 and 2030. These targets are aimed at achieving a more competitive, secure and sustainable energy system. A specific target has established that at least a 27% share of renewable energy consumption must be achieved. In this context, biogas/biomethane production plants can be strategic, and therefore particular attention has to be paid for their safe operation. In fact, biogas industry is experiencing fast growth worldwide. However, the number of accidents in biogas production is growing even faster. The estimated risk profile of biogas production confirmed that its production process presents a non-negligible risk. Accident analysis can improve the safety of such plants. In particular, creation of an accidents report can be strategic in order to individualize the more hazardous operations and elements which require a specific maintenance schedule. Indeed the decrease of number of accidents, which occurred in the biogas production plants, could be easily achieved by adapting the process safety experience acquired in other industrial sectors. With regard to this topic, it is important to remember that the typical culture of the farming is far enough from industrial approach and therefore it requires clear and useful tools, which are able to address both elements—maintenance and operation. The safety checklist can meet these requirements, because it is a practical tool, which can be used to carry out the analysis of hazards of biogas plants. Starting from a scientific analysis of preventive and protective measures, the checklist has been designed to assess the actual safety levels of the biogas plant and to support the operators in order to improve the safe process management. Furthermore, the development and application of specific safety standards to the biogas sector would be beneficial to avoid design and operational errors.

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